X-ray Variability during Optical Eclipses of a Young Binary System

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Abstract

We report on the XMM-Newton observations of the young eclipsing binary system TY CrA, performed during the primary eclipse on 2003 March 28 for about 36 ksec and the following secondary eclipse on 2003 March 29 for about 32 ksec. The observations were intended to search for X-ray eclipses to identify the X-ray emitter, but we detected no X-ray eclipse in these optical eclipses. Instead, we detect a flux increase during the primary eclipse, which does not look like conventional solar-type X-ray flares and seems to coincide with the optical eclipse, while we detect no X-ray variation specific at the secondary eclipse. Surprisingly, between these two eclipses, the plasma temperature in the hot component and X-ray luminosity significantly dropped from 3.3 keV to 1.5 keV and from 2.7 x10^{31} ergs s^{-1} to 10^{31} ergs s^{-1}, respectively. Whereas the absorption column density (N_H) did not vary (~4.5x10^{21} cm^{-2}). We discuss the origin of the X-ray emission combining results of earlier observations with ASCA, Chandra and XMM-Newton.

Introduction

Intermediate mass pre-main-sequence stars (Herbig Ae/Be stars: HAeBes) are:

- High mass analogues of T-Tauri stars (M ~3-8 M_{solar}, Age: 0.1-1M years).
- X-ray emitters (kT ~2 keV, Lx ~1e29-1e31 ergs s^{-1}) (Zinnecker & Preibish 1994).

No conventional mechanism seems to be applicable to X-ray emission from HAeBes.

- No surface convection zone to generate solar-type dynamo.
- No strong UV field to accelerate unstable stellar winds.

➔ Magnetic activity through mass accretion may take a role (Hamaguchi 2001).

However, HAeBes often accompany low mass companions (Testi et al. 1998).

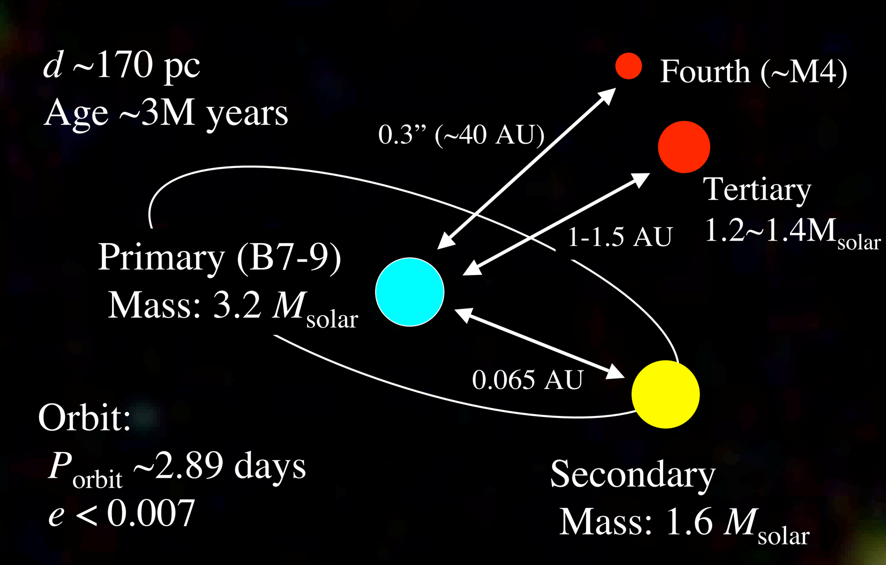
- Such low mass stars could actually produce the observed X-ray emission.

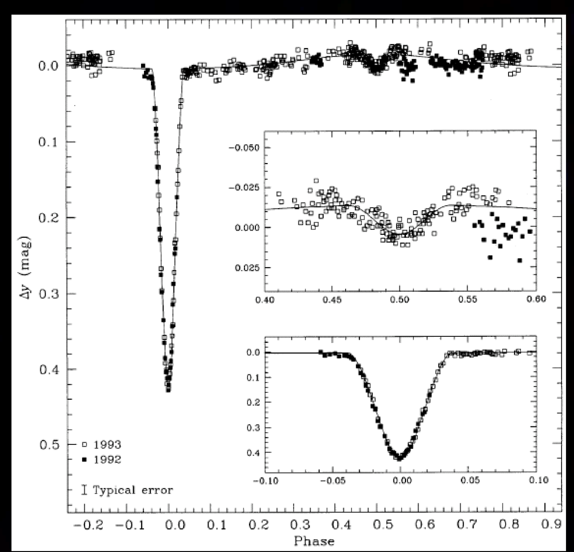
➔ Observation of an eclipsing HAeBe binary system to look for an X-ray eclipse correlated with an optical eclipse of the primary or secondary.

TY CrA: the only HAeBe eclipsing binary system well studied.

- ASCA observations (1994-1998): kT~ 1.8 keV, L_X ~5e30 ergs s^{-1} (Hamaguchi et al. 2004)

TY CrA Binary (Multiple) System





Optical light curve: Casey et al. (1998)
Other references are Casey et al. (1995), Corporon et al. (1996), Knude & Hog (1998), and Chaubin et al. (2003).

XMM-Newton Observations

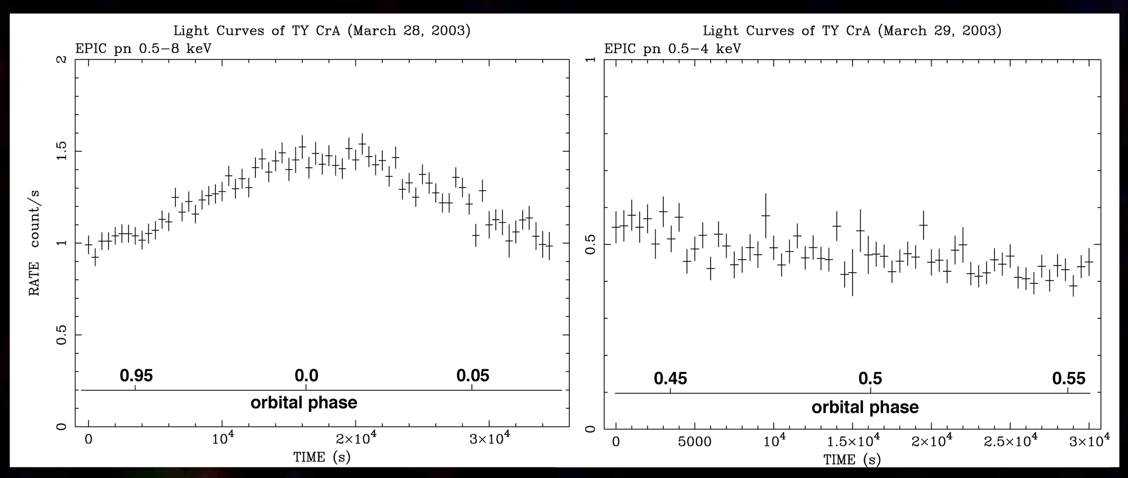
Primary eclipse (Obs_{pr}): March 28, 2003 (37 ksec)
Secondary eclipse (Obs_{sec}): March 29, 2003 (33 ksec)

Results

Light Curves

No X-ray eclipse was observed during Obs_{pr} and Obs_{sec}

- Obs_{pr}: Instead, X-ray flux increased by a factor of two apparently coincident with the optical eclipse timing.
- Obs_{sec}: Count rates decreased a factor of two from Obs_{pr}. X-ray flux gradually decreased during the observation.



EPIC pn Light curves in Obs_{pr} (*left*, 0.5-8 keV) and Obs_{sec} (*right*, 0.5-4 keV). Orbital phases 0 and 0.5 are optical eclipses of the primary and secondary, respectively.

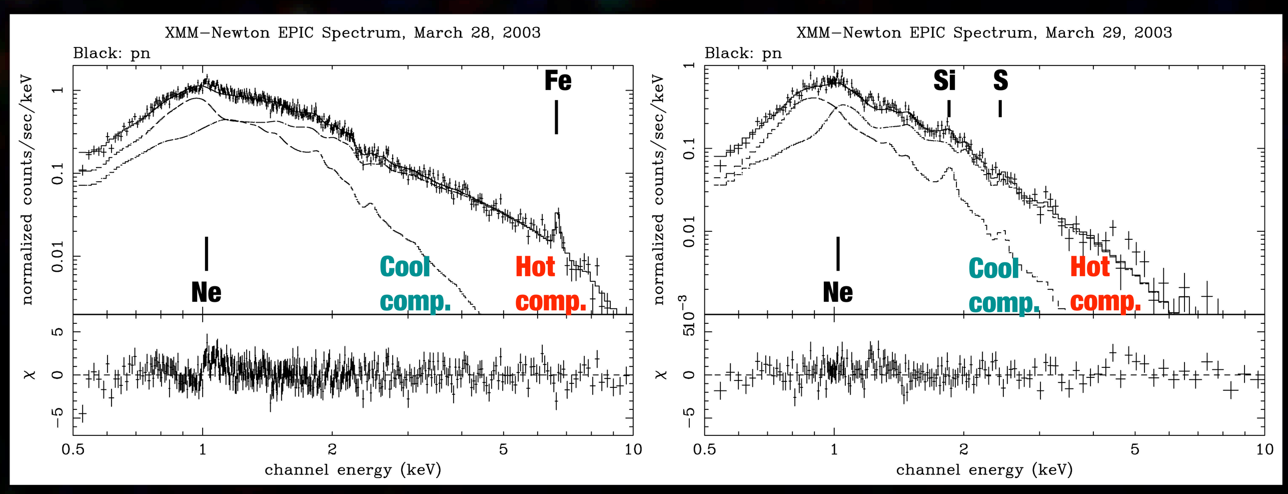
Caption of the background Image

X-ray true color image of the R CrA region combined of Obs1 and Obs2. Image is color coded to represent hard band (3-9 keV) to blue, medium band (1-3 keV) to green and soft band (0.2-1 keV) to red. The brightest central source is TY CrA.

Spectra

Both spectra of Obs_{pr} and Obs_{sec} need at least 2-temperature components

- The kT_{hot} (~1.5 keV) and L_X (~1e31 ergs s^{-1}) in Obs_{sec} were similar to the ASCA result (hereafter, the low state: LS). While, the parameters in Obs_{pr} (kT_{hot} ~1.5 keV, L_X ~ 1e31 ergs s^{-1}) were higher. (the high state (HS).
- Cool plasma temperature did not change strongly.
- Hydrogen column density (N_H) was unchanged.
- Metal abundance was small ~0.2-3 solar.



EPIC pn spectra in Obs_{pr} (*left*) and Obs_{sec} (*right*).

Table : Spectral Parameters Fit by an Absorbed 2T Model

		Obs_{pr}	Obs_{sec}
Cool component			
kT	[keV]	0.85 (0.84–0.87)	0.68 (0.66–0.70)
Flux	[ergs cm^{-2} s^{-1}]	8.7e-13	4.0e-13
Hot component			
kT	[keV]	3.3 (3.1–3.5)	1.5 (1.47–1.58)
Flux	[ergs cm^{-2} s^{-1}]	3.8e-12	8.2e-13
Abundance	[solar]	0.18 (0.13–0.22)	0.28 (0.24–0.32)
N_H	[10^{21} cm^{-2}]	4.3 (4.2–4.5)	4.6 (4.3–4.9)
L_X	[ergs s^{-1}]	2.7e31	9.9e30
$\Delta\chi^2$ (d.o.f.)		1.26 (916)	1.15 (458)

Note — Number in parentheses shows 90% confidence errors.

Discussion

1. No X-ray eclipse was found during the optical eclipses.

- Could the X-ray emission be from the third and fourth companions?

➔ L_X of low mass stars are less than 1e31 ergs s^{-1} (Stelzer & Neuhauser 2001). The observed X-ray emission were too large for a low mass star.

- Around 30% of the star, including the polar cap, is covered during the eclipses.

➔ X-ray emission would not come from the polar cap.

- If the X-ray emission comes from a spherical coronae,

➔ the radius should be >1.5 R_{star} not to see significant flux decrease during the observations.

2. What was the flux increase in Obs_{pr}?

- Rotational modulation of an active hot spot on the primary or secondary star (i.e. an active hot spot on the primary or secondary surface appeared from back of the star by stellar revolution, rotate 180degree and disappears to the back again).

➔ Rotation of both the primary (sub-synchronous rotation, P >2.89 days) and secondary (synchronous rotation, P >2.89 days) stars is too slow to show such time variation.

- Magnetically generated X-ray flare?

➔ The light curve shape is not like such an X-ray flare, seen on the Sun and young stars.

In another XMM-Newton observation in 2001, similar flux increase (just during the rising phase) apparently coincident with the secondary eclipse was observed. The kT_{hot} (~4.5 keV) and L_X (~4e31 ergs s^{-1}) suggests it to be in HS.

- The flux increase might relate to HS. The increase could occur both during the primary and secondary eclipses.

➔ X-ray emission might be stronger to the direction parallel to the primary and secondary stars during HS. The possible mechanisms are

- Thick absorbing matter is open to that direction, but it is unlikely because variation of N_H required for the flux variation was not observed.
- X-ray emission is produced by inverse Compton process. Stellar UV excites to the X-ray energy by high energy electrons γ ~20 streaming parallel to the axis on the primary and secondary stars. In fact, continuum spectra of both Obs_{pr} and Obs_{sec} can be reproduced by an absorbed power-law model as well, but line emission requires a thermal component as well.

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